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Resolutions of Several Puzzles at Intermediate p_T and Recent Developments in Correlation

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Abstract

Some of the puzzles on hadron production at intermediate p_T found at RHIC are explained as natural consequences of parton recombination. In that framework for hadronization the correlation among hadrons produced in jets can be calculated. Some new results on both near-side and away-side jet structures are presented.

1 Introduction

The traditional way of treating hadronization is by means of fragmentation. That has been found to lead to gross disagreement with the data on hadron production in the $3 < p_T < 8$ GeV/c range at RHIC. It has already been pointed out at Quark Matter 2004 that the p/π ratio can be understood in the recombination model [1, 2]. I now present several other puzzles when interpreted in the fragmentation model, but they can readily be resolved in the framework of parton recombination. In that framework correlations in jets can also be calculated. With or without triggers, correlation between two hadrons can be studied either in p_T or in $\Delta\eta$ and $\Delta\phi$. The most recent result from work still in progress is the simulation of tracks of hard partons traversing the dense medium, showing the dip-bump structure on the away-side in $\Delta\phi$ but turning to a peak at higher parton momentum.

2 Several puzzles and their resolutions

The p/π ratio in Au+Au collision was found to exceed 1 at $p_T \approx 3$ GeV/c [3], a phenomenon that contradicts fragmentation, since the fragmentation function for proton is much less than that for pion. Fragmentation is not an important process at low and intermediate p_T because recombination that involves the soft thermal partons is the dominant process [4]. When thermal-shower parton recombination is considered, the data on the p and π spectra can be well reproduced, and thus the p/π ratio also [5].

A similar phenomenon occurs in d+Au collisions. The A dependence of the p_T spectra is conventionally referred to as the Cronin effect, [6] which has become synonymous to p_T broadening by multiple scattering in the intial state. If the A dependence is due to the initial-state effect, and not to hadronization in the final state, then that

effect should be independent of the species of the hadron detected. But the data indicate otherwise [7, 8]. Again, in the recombination model it has been possible to obtain $R^p_{CP} > R^\pi_{CP}$ for d+Au collisions in agreement with the data [8].

Another related phenomenon is the forward-backward asymmetry in d+Au collisions. If the transverse broadening of the initial partons is impotant, then there is more broadening in the forward (F) direction than in the backward (B) direction. Thus B/F should be < 1. But the data show $B/F > 1$ for $1 < p_T < 5$ GeV/c [9]. Since there are more thermal partons in the B direction than in the F direction, thermal-shower recombination leads naturally to $B/F > 1$. In fact, the data on R_{CP} for $\eta = 0$ to 3.2 [10] can be well reproduced in the recombination model [11]. That is significant because no new physics has been inserted in going from the backward to the forward direction, in contrast to the approach based on saturation physics [12].

The final puzzle we mention here is the difference of the associated particle distributions (APD) in central AA and pp collisions on the same side as the trigger [13]. Even with medium-modified fragmentation function it seems hard to accommodate a factor of 3 difference at $p_T \sim 1$ GeV/c. That is readily obtained in the recombination model due to the abundance of thermal partons at low p_T in AA collisions [14].

3 Correlations of hadrons in jets

Since hadronization by recombination has been found to be so successful in HIC, it is natural to exend the study to correlations among hadrons in jets produced at RHIC. There are various ways of studying correlation; they can be divided into two classes. One is to use a trigger and study the APD in various variables. The other is to treat two hadrons on equal footing without designating one of them as trigger.

3.1 Correlations using trigger

There exist data that show the $\Delta\eta$ and $\Delta\phi$ dependences of the AP. On the near side it is found that a peak in $\Delta\eta$ sits on top of a flat background, called the pedestal [13]. There is no such pedestal in the $\Delta\phi$ distribution, mainly because of the subtraction scheme that forces the APD to vanish at $|\Delta\phi| = 1$. In [15] the pedestal is interpreted as the result of the conversion from the hard parton's energy loss to the thermal energy of the neighboring soft partons, which in turn enhance the multiplicity of the AP. Since the energy loss of a hard parton is proportional to the distance it traverses in the medium, lower trigger momentum allows the hard collision to occur farther away from the surface than a trigger with higher momentum. Thus if our interpretation of the pedestal is correct, then we expect the pedestal to disappear as the trigger momentum is increased, since hard partons created nearer the surface lose less energy on their way out. There is some hint in the data that the pedestal is diminished at higher trigger momentum [16].

On the away side the $\Delta\phi$ distribution has stimulated considerable interest because it gives information on the nature of jet quenching. The observation of a dip at $\Delta\phi = \pi$ and bumps on the two sides at $\Delta\phi \sim \pi \pm 1$ when the trigger momentum is less than 4 GeV/c [13, 17] seems to support the idea of collective response from the medium to the passage of a hard parton, such as a shock wave. However, such an explanation would encounter difficulty, if the dip-bump structure disappears at higher trigger momentum.

We have considered the problem by simulating parton rescattering track-by-track based on a Gaussian distribiton of scattering angle at discrete points in the dense medium, the distance between two successive points being dependent on the average local density and the parton momentum [18]. With a specific criterion for the termination of a track, it is found that most trajectories directed toward the center of the medium are totally absorbed. The ones that emerge have initial directions away from the center and undergo successive scattering with deflections persistently farther away from the center; they are the tracks that give rise to the bumps at $\Delta\phi$ away from π, as observed in the data. The lack of straight-through trajectories causes the dip at $\Delta\phi = \pi$. The absorbed tracks enhance the thermal partons and lead to higher multiplicity of the soft hadrons that lift the base of the dip. This scenario is changed as the initial parton momentum is increased, since more trajectories punch through the medium, resulting in a peak rather than a dip. There exists preliminary evidence for such a change in the $\Delta\phi$ distribtion in the RHIC data as the trigger momentum is increased [19].

3.2 Correlation without trigger

The other class of correlation studies is the direct analysis of the correlation function $C_2(1,2) = \rho_2(1,2) - \rho_1(1)\rho_1(2)$, where ρ_1 and ρ_2 are the one- and two-particle distributions. If the focus is on the correlation between the p_T values of the produced hadrons, there is no need for any subtraction of background beyond what is explicit in the definition of $C_2(1,2)$. On the other hand, if the interest is on the $\Delta\eta$ and $\Delta\phi$ distributions without treating one of the two hadrons as the trigger for reference, then autocorrelation is the quantity for investigation, as pioneered by Trainor and collaborators [20, 21]. We have some results on both of these types of correlations on the same side of a jet.

For correlation in p_T our main result is that C_2 is negative for p_T around 2 GeV/c in Au+Au collisions at 200 GeV [22]. The reason for the anti-correlation is that the shower partons in a jet are anti-correlated, if it is assumed that the shower partons are dynamically independent, but kinematically constrained due to momentum conservation. Since thermal-shower recombination is the dominant component at intermediate p_T, the pion C_2 is therefore also negative. At p_T higher than 3 GeV/c the $\rho_1(1)\rho_1(2)$ part of $C_2(1,2)$ becomes more severely damped due to the double appearance of the hard scattering cross section, one in each ρ_1, whereas ρ_2 has only one; hence, $C_2(1,2)$ becomes positive, though very small. No data are available yet to verify this prediction. If no dip is found in $C_2(1,2)$, it may mean that there exists dynamical correlation of the shower partons in a jet not yet incorporated.

Finally, we report here the recent result of our study of autocorrelation, $A(\eta_-, \phi_-)$, where η_- and ϕ_- are the differences of η and ϕ of the two particles, all other variables being integrated over. The difference angular variables are related to the angle χ between the momentum vectors of the two particles, which is the key link to the parton dynamics. Since the momentum of the shower parton and that of the pion that it forms with a thermal parton are collinear, the angle χ between the two pions is the same angle between the two corresponding shower partons, whose angular distributions relative to the jet axis can be described by a Gaussian with a width σ. Thus for every σ it is possible to determine the autocorrelation distribution $A(\eta_-, \phi_-)$ [23]. The data on $A(\eta_-, \phi_-)$, when they become available, can then be used to deduce phenomenologically the value of σ, thereby revealing a basic property of the jet cone.

4 Conclusion

The recombination model has succeeded in resolving several puzzles at intermediate p_T in HIC and makes possible detailed calculations of various expressions of correlations in jets. So far no features of the RHIC data have presented any difficulty for this mechanism of hadronization to explain. For very high p_T in excess of 10 GeV/c shower-shower recombination becomes more important, and that is equivalent to fragmentation [5]. The region that best exhibits the interaction between a hard parton and the dense medium is at intermediate p_T.

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